International Council
for the
Exploration of the Sea

C.M. 1998/R:11
Theme Session on Mesoscale Physical Phenomena and
Biological Production: Implications for GLOBEC

The vertical distribution of ichthyoplankton in relation to the hydrographic conditions in the Eastern Baltic

Andrei Makarchouk
Latvian Fisheries Research Institute, Daugavgrivas St., 8, Riga, LV-1007, Latvia, andrei@latfri.lv
Hans-Harald Hinrichsen
Institute of Marine Science, Düsternbrooker Weg, 20, 24105, Kiel, Germany, hhinrichsen@ifm.uni-kiel.de

Abstract

The vertical distribution of eggs and larvae of cod (*Gadus morhua callarias*), sprat (*Sprattus sprattus balticus*) and four-bearded rockling (*Onos cimbrius*) has been investigated in the Gdansk Deep and the Gotland Basin in May - June and July - August 1996 and 1997. Sprat eggs occurred in the wide range of depth, but cod eggs were restricted to a tiny water layer. Mean depth of cod eggs was 95 - 87 m in the Gdansk Deep and 112 -95 m in the Gotland Basin. More cod eggs than expected were found at low salinity in the period of most intensive spawning: up to 5% at 9 psu and 22 % at 10 psu in July 1996 and 8% at 10 psu in July 1997. Mean depths of sprat eggs diminished from 81 m in spring to 58 m in summer in the Gdansk Deep and from 94 m to 65 m in the Gotland Basin. At the same time sizes of sprat eggs also decreased. Most of the eggs were found at the depth of the pycnocline. No significant differences in mean depths of eggs of sprat at different stages of development were discovered. Reduction in mean diameters of sprat eggs with depth and density was observed. In contrast, sizes of cod eggs showed no clear tendencies to change either from spring to summer or with changes in water density.

Introduction

Knowledge about the vertical distribution of pelagic fish eggs and larvae is very important for evaluation of ambient water conditions. It is also important for understanding the mechanisms of interactions between different animals including feeding on pelagic fish eggs and larvae by different organisms, and is a pre-requisite for utilisation of physical circulation models being capable to calculate the transport of fish eggs and larvae. The vertical distribution of ichthyoplankton was investigated and described in the regions of the Atlantic ocean including the Baltic Sea, mainly in the Bornholm Basin (i.g. Wieland 1995, Wieland and Zuzarte 1991, Horbova and Wlodarczyk 1995). We tried to follow patterns of vertical distribution of eggs and larvae of sprat, cod and rockling in the Gdansk Deep and the Gotland Basin and assess possible influence of water structure and parental effects on it.

Material and methods

Sampling was carried out in the central parts of the Gdansk Deep and the Gotland Basin (Table 1) using BIOMOC multiple opening/closing net (mesh aperture 335 µm, mouth opening 1 m²) operating with 9 nets and equipped with flowmeter (see for the detailed description Wieland 1995). At the sampling positions hydrographic measurements (temperature, salinity, density, oxygen) were performed with a ME OTS 1500 CTD/O2 probe. BIOMOC was towed at a definite depth for 3 minutes at a speed of 3 knots, volume of water filtered through each net was ca. 300 m³. Two combined hauls of BIOMOC (15 nets in the Gdansk Deep and 17 nets in the Gotland Basin) allowed to investigate the vertical distribution of ichthyoplankton in the water column down to the bottom (100 m) in the Gdansk Deep and to 140 m in the Gotland Basin with a resolution of 10 m in the upper part of the water column. At depths where highest concentrations of fish and especially cod eggs and larvae were expected a vertical resolution of 5 m depth intervals was chosen. These combined hauls have been repeated thrice at every sampling site.
Samples were fixed in 4% buffered formaldehyde-sea water solution and processed within 10 months time. All the eggs and larvae were counted. At least 100 eggs (or all of them if less than 100 in

sample) were processed for measuring and determination of stages of development. Stages of development of eggs were determined according to the 4-stage system by Rass and Kazanova (1965). Eggs on each stage were divided into alive and dead ones. Diameters of fish eggs were measured under the stereoscopic microscope with the precision of 0.025 mm. If the eggs had irregular shape, lesser diameter was measured. Total lengths of fish larvae were measured to the nearest 0.5 mm length classes. The number of larvae never exceeded 100, so all the larvae found were measured. The mean depth of eggs was calculated as follows: $h_{mean}=\sum (p_i h_i)$, where p_i was a relative abundance of eggs in stratum i and h_i was depth of stratum i.

Table 1. BIOMOC haul information.

Basin	Date	Latitude	Longitude	Depth, m
Gdansk	22/05/96	55°00'	19°04'	100
Gotland	29/05/96	56°54.7'	19°53.9'	171
Gdansk	25/07/96	54°53'	19°11.7'	106
Gotland	03/08/96	56°55.1'	19°53'	170
Gdansk	02/06/97	54°54.1'	19°11.9'	104
Gotland	08/06/97	56°55'	19°53'	169
Gdansk	24/07/97	54°54'	19°11.8'	107

Results

Hydrological situation

For the years 1996 and 1997 the hydrographic conditions in the Gdansk Deep and the Gotland Basin are represented in Figs. 1 and 2. Due to atmospheric heating in spring and summer, in both basins a thermocline was developed between 10 and 30 m separating warmer surface water masses from the old winter water. In the Gdansk Deep the halocline was situated between 60 and 80 m and within the central Gotland Basin between 70 and 110 m. In the latter, below the halocline the oxygen concentration decreased rapidly to values < 0.1 ml/l. In 1996 in both basins the halocline and winter water masses showed low temperatures and relatively high oxygen concentrations. During the winter period well oxygenated water masses had been advected from the western Baltic through the Bornholm Basin and the Stolpe Trench into the Gdansk Deep and led to an improvement of the environmental conditions of the bottom water. In contrast to observations obtained during cruises in 1996, in June and July 1997 the bottom water in the Gdansk Deep was almost oxygen depleted. Generally, the temperature of the halocline and of the old winter water mass was higher compared to observation obtained in 1996.

General results

Cod eggs were found in considerable numbers only in the Gdansk Deep in July -August but to a lesser extent also in May - June. On the contrary rockling eggs were numerous mainly in the Gotland Basin in summer time. Sprat eggs prevailed in both investigated regions all the time.

Table 2. Changes in the mean depth of sprat eggs and their size at different time of the year and also coupling of egg abundance with oxygen conditions.

Basin	Date	Mean depth of eggs, m	Mean diameter of eggs, mm	Water density (Sigma-t) in the mean depth of eggs, kg/m³	Sea surface temperature	Share (%) of eggs in the water with oxygen content less than: 5 ml/l	2 ml/l	1 ml/l
Gdansk	22/05/96	81	1.486	8.57	5.4	75		
Deep	02/06/97	72	1.452	7.85	7.3	85	15	
	25/07/96	64	1.436	6.222	15.9	9		
	24/07/97	58	1.414	5.914	17.9	3	2	
Gotland	29/05/96	94	1.483	8.26	5.3	92	81	11
Basin	08/06/97	77	1.492	7.25	10.1	48	31	7
	03/08/96	65	1.404	6.59	16.1	23	13	11

The number of pelagic fish eggs and larvae strongly varied between the 3 parallel hauls at each sampling location, which corroborated opinion about great patchiness of the ichthyoplankton distribution. Sometimes the standard deviation exceeded the mean value, which was typical for fish larvae and to the lesser extend for cod and rockling eggs, i.e. for organisms which abundance was rather low.

From other species only sand goby (*Pomatoschistus minutus*) larvae were abundant. They stayed mainly at the 10 m depth in the summer time in both basins, and only in July 1996 they were numerous also in the lower part of the Gdansk Deep. Larvae of flounder (*Platichthys flesus*) and sea snail (*Liparis liparis*) occurred seldom in the upper layers in spring.

Sprat

Eggs of sprat were found in the wide range of depths and their vertical distribution was close to normal one (Figs. 3 and 4). Main difference between two regions was in the larger mean depth of eggs in the Gotland Basin, especially in summer. Number of sprat eggs in 1997 exceeded corresponding values in 1996 in all regions and months, especially in the Gdansk Deep in spring. In the course of the spawning period mean depth of eggs has decreased (Table 2). Mean depths of eggs on different developmental stages did not change much. At least any clear tendency was not found. Mean diameters of sprat eggs also diminished with time (Table 2) in both regions, especially in the Gotland Basin.

Sprat eggs developed at the wide range of temperature, salinity and oxygen content (Table 3). However this table does not give a full notion about temperature conditions: the lowest temperature usually was measured in the intermediate water mass at a depth of about 60 m. The oxygen content in the water layer where sprat eggs occurred in the Gotland Basin was higher in spring 1997 compared with the corresponding period of 1996 (Table 3), but in the Gdansk Deep it became slightly worse. In general, the oxygen conditions for sprat eggs improved from spring to summer. It happened because the depth where sprat eggs appeared reduced with time.

In general size of sprat eggs diminished with increasing water density (Fig. 7). The distribution of egg diameters according to the depth and thus according to the water density was rather complicated: sizes of eggs decreased mainly in the upper part of the pycnocline, but they remained relatively constant or even changed in reverse order in the other parts of water column.

Sprat larvae showed 3 peaks in their distribution (Figs. 5 and 6): close to the water surface, at the depth of permanent pycnocline (in its upper part), where eggs were most numerous, and either near the bottom (in the Gdansk Deep), or in the deepest part of the investigated water column. The vertical distribution of sprat larvae of different lengths was analysed if the abundances were high enough, i.e. in June 1997 in each of the basins (Fig. 8). In the Gdansk Deep the smallest larvae were found mainly in the deepest part of water column and to a lesser extent in the upper part of it. Highest amounts of larvae were discovered in the deepest layers, where saturation with oxygen was rather poor at that moment (slightly more than 1 ml/l). These larvae were small: from 4 to 6.5 mm in the main. Almost all the largest larvae (length more than 7 mm) concentrated at 10 m depth (the shallowest investigated layer).

Table 3. Hydrological conditions at the upper and lower surfaces of a water layer containing 80% of fish eggs. Only those periods and basins were taken into account when eggs had been abundant.

Species	Region	Date	Depth, m		Temperature		Salinity, psu		Oxygen, ml/l	
Sprat	Gdansk	22/05/96	55	95	1.8	2.5	8.0	12.2	7.5	5.0
	Deep	25/07/96	45	80	8.4	3.2	7.3	9.1	7.7	5.5
		02/06/97	60	85	3.4	5.1	7.5	9.0	6.6	1.9
		24/07/97	43	65	4.2	3.6	7.3	7.8	8.0	6.7
	Gotland	29/05/96	68	120	3.95	4.7	8.7	11.1	3.9	1.1
	Basin	03/08/96	38	105	4.1	4.7	7.4	10.6	7.7	1.4
		08/06/97	49	100	3.7	4.6	7.3	10.4	8.4	1.3
Cod	Gdansk	25/07/96	85	98	3.1	2.9	10.1	11.7	4.7	3.0
	Deep	02/06/97	87	98	5.2	5.3	11.5	12.0	1.6	1.6
		24/07/97	80	95	4.9	5.1	11.1	12.3	2.7	1.5
Rockling	Gdansk	22/05/96	90	100	2.2	2.6	11.6	12.4	5.5	4.8
	Deep	25/07/96	80	90	3.2	2.9	9.1	11.1	5.5	3.8
	Gotland Basin	03/08/96	52	110	3.2	4.8	7.7	10.8	7.1	1.0

In the Gotland Basin the smallest, recently hatched, larvae were found mainly at 60 - 75 m depth - in the upper part of the pycnocline and at the same time at the depth of the highest abundance of eggs. Other small larvae (length 4 - 6.5 mm) contributed to 2 peaks in abundance: in the layers of 60 - 80 m and 105 - 130 m. Large larvae (longer than 7 mm) were found at different depths but they predominated in the layers of 40 and 50 m.

Cod

Cod eggs were distributed in the lower parts of the water columns, in the case of the Gotland Basin they were found as deep as it was possible (Table 3) due to the critical limits of oxygen for successful egg development (Westin & Niesling, 1991; Wieland *et. al.*, 1994). The abundance of the cod eggs increased from May - June to July - August.

The oxygen conditions were not favourable, even inside rather thin layer in the Gdansk Deep where cod eggs were abundant in summer: in 1996 95% of all eggs were found in the layer with oxygen contents < 5 ml/l, but in 1997 already 99% of all eggs were found in this layer, and 74% in the water with oxygen contents ≤ 2 ml/l.

Most of cod eggs were found here at the depth where salinity was > 11 psu. Sometime considerable proportions of them were sampled in the water layer with the lower salinity though: on 24 July 1996 55% of all eggs were in the water with salinity ≤ 11 psu, but 27% - in the water with salinity ≤10 psu, and on 25 July 1997 7.7% of cod eggs were found at 75 m depth with salinity of 10.1 psu.

No large differences were found in the mean depths of eggs on the different stages of development. Furthermore, there was no significant difference in egg size in spring and summer (Tab. 4).

In 1997 cod eggs were distributed at a wider range of depths, than it had been in the end of July 1996: 75 - 100 m in 1997 and 85 - 100 m in 1996 (Figs. 3 and 4). Significant differences in cod eggs diameters according to depth or water density were not observed (Fig. 7).

Number of cod eggs in the Gotland Basin was very low (Table 4), and so qualitative analysis here was not possible. Mean depth of cod eggs fluctuated here from 94 to 112 m.

Generally, the number of cod larvae was very low (Total number 15). In the Gdansk Deep they were found usually just above the halocline or inside it (depth 55-88 m), and only in summer. They were 4.5 - 5.5 mm long. Only 2 cod larvae were caught in the Gotland Basin, both of them in August 1996.

Table 4. Changes in the mean depth of cod eggs and their size at different time of the year.

Basin	Date	Mean depth of eggs	Mean diameter of eggs, mm	Water density (Sigma-t) in the mean depth of eggs	Sea surface temperature	Total number of eggs	Number of measured eggs
Gdansk	22/05/96	95	1.764	9.79	5.4	203	203
Deep	02/06/97	93	1.731	9.28	7.3	655	601
	25/07/96	92	1.730	9.01	15.9	4459	1591
	24/07/97	87	1.748	9.38	17.9	3371	1803
Gotland	29/05/96	98	1.708	8.33	5.3	16	16
Basin	08/06/97	112	1.718	8.60	10.1	49	48
	03/08/96	94	1.722	8.08	16.1	80	70

Rockling

Rockling eggs appeared in our samples only in summer (Figs. 3 and 4). In the Gdansk Deep they were found at the same depth as cod eggs, but in the Gotland Basin they were found in August 1996 in considerable numbers up to 40 m depth, where water salinity was <8 psu. The highest concentrations of the rockling eggs were observed in the upper part of permanent pycnocline.

Discussion

We suppose that the character of the vertical distribution of sprat eggs is more or less the same for the deepest parts of the Gdansk Deep and the Gotland Basin. The hydrological structure of water column was very similar in each of these regions during time of the surveys. It was noticed that the horizontal distribution of sprat eggs followed the bottom topography. E.g. in May - June the border of high abundance of sprat eggs in the Gotland Basin reflects the 70 - 80 m isobath (Makarchouk 1996). If the sprat eggs spawned over different depth strata have similar mean buoyancy those which could be spawned in the shallower places must sink to the bottom in the main.

Temperature conditions in 1996 and 1997 differed in both basins (Figs. 1 and 2). Sprat eggs can develop at the wide range of salinity (Grauman 1980), so it is not the limiting factor for the success of sprat spawning. Temperature conditions and oxygen content seem to be more important for them, and the temperature in the intermediate water layer where sprat eggs were mostly numerous was extremely low in the end of May 1996: < 2° in the Gdansk Deep (depth 50 - 70 m) and slightly higher than 2° in the Gotland Basin. Temperature conditions in this layer in the beginning of June 1997 were more favourable. Bad temperature conditions in 1996 could be one of the major reasons for the poor recruitment of sprat that year. It might be probable that the successful spawning of sprat in the beginning of the spawning period contributes more to rich year-class than the spawning in the later period of year. First, early hatched larvae have better opportunity to grow big before winter comes and thus easier survive the winter, and secondly, there is high probability that the peak of spawning of zooplankton could coincide with the beginning of feeding of larvae thus securing their growth and survival. Thus we suppose that the influence of the temperature conditions in the intermediate water layer in spring on the success of sprat spawning is worth to be investigated.

The depth of the distribution of fish eggs depends mainly on ambient water density and the buoyancy of the eggs. The results based on our samples showed that the sprat eggs obtained neutral buoyancy at 8.57 kgm^{-3} water density in the end of May, but in the end of July at less than 6 kgm^{-3}. Mean diameters of sprat eggs decreased during the same period of time. The fact that sprat eggs sizes became smaller from the beginning towards the end of spawning period was noticed by many scientists (Grauman, 1980). So, it must be the evidence that specific gravity of sprat eggs diminishes during the spawning period. Nissling and Westin (1991a) showed that the specific gravity of cod eggs from subsequent batches from the same female decreased. Furthermore, Nissling *et. al.* (1994) discovered that cod egg buoyancy significantly correlated with yolk osmolality and chorion thickness and only weakly correlated with egg size. Coombs *et. al.* (1985) observed an increase in density of eggs of sprat during development, but they did not found clear change of vertical distribution with stage of development. It is in accordance with our findings that there were no significant difference in mean depth of sprat eggs on different stages of development.

It is widely believed that the terms of spawning period of sprat depend upon water temperatures during winter, spring and summer. That is why we used sea surface temperature (Tables 2 and 4) as a rough indicator of how far the spawning season had proceeded. Both mean depth and mean size of sprat eggs have reduced more in the Gotland Basin. The spawning season in this region is shorter than in the Gdańsk Deep and changes during the same period must be larger there. In case of mean depth of eggs changes in the Gotland Basin were not as big as they were in the Gdansk Deep: water is more stratified in the latter, and changes in terms of density of ambient water were even greater there.

Sprat larvae begin to feed at the length of 5-6 mm after consuming the yolk sack (Grauman 1984). It looks very likely that those larvae which remained at the big depth would not succeed in feeding even if they were not influenced by poor oxygen conditions there, because light irradiance at the big depth does not allow to see prey organisms (Grønkjær and Wieland 1997). Thus, migration to the surface layer seems to be a prerequisite for further survival of sprat larvae. It is in accordance with previous findings: sprat larvae sampled in the water surface layer (0 - 1m) were reported to be larger than those sampled in the whole water column (Makarchouk 1997). Sprat larvae are found in the surface layer in the Eastern Baltic in considerable numbers from April, later their amount increases (Grauman 1984, Makarchouk unpublished data).

Rockling and especially cod eggs are restricted to the deepest parts of the basins. No large differences were observed in both the mean depth of cod eggs and their sizes during the spawning season. It was in contradiction to what Grauman (1984) had wrote: she had found that size of cod eggs had decreased continually in all regions of the Baltic from spring to autumn. The explanation of this was that younger females spawning later in the year than the older ones were producing eggs of smaller size. There is some indication that both mean depth and mean size of sampled cod eggs were more influenced by hydrological conditions rather than by parental effects in 1996 and 1997 in the Gdansk Deep. For example, in 1997 cod eggs here were even larger in the end of July than almost 2 months earlier. It could be the result of very unfavourable hydrological conditions when smaller eggs did not survive due to sinking into the oxygen deficient layer. In time of our investigation cod eggs were restricted to a tiny layer and very probable that all eggs which did not meet certain conditions simply did not survive.

In the laboratory experiments Baltic cod eggs obtain neutral buoyancy at 14.4 psu (Nissling and Westin 1991a). The measurements were made at 7° water temperature and at pressure existing at the sea surface. Assuming that neutral buoyancy of egg depends on water density, we took into account temperature and pressure at the depth where cod eggs were abundant. In the Gdansk Deep and the Gotland Basin for the depth 87-98 m and temperature 5° the density at which eggs were neutrally buoyant in the experiment (i.e. 1011.24 kgm^{-3}) must be achieved at 13.7-13.6 psu (for the depth 60-72 m salinity values must be ca. 13.85-13.78 psu). In the Eastern Baltic such a big salinity was not found at present and we can expect that only a small number of eggs with much higher buoyancy due to either bigger size or to lower density are surviving at much lower salinity. Grauman (1984) wrote that only large eggs of cod survived in the years with bad hydrological situation. Mean size of eggs increased in these years, but the standard deviation reduced. Unfortunately we could not compare results of our measurements of mean size of cod eggs with the ones reported by Nissling and Westin (1991a) precisely , because they had made measurements of alive eggs, but we had measured eggs which had already been fixed in formalin and therefore had shrunk.

Acknowledgements

The authors gratefully acknowledge great efforts of all scientists on board Alkor and especially Drs. F.W. Köster and K. Wieland, Institut für Meereskunde Kiel in sampling of these materials, there help and advices. This work was funded by EU CORE project. Composing of materials and writing of this paper was partly financed from BASYS project.

References

Coombs, S.H., C.A. Fosh and M.A. Keen, 1985. The buoyancy and vertical distribution of eggs of sprat (*Sprattus sprattus*) and pilchard (*Sardina pilchardus*). J. mar. biol. Ass. U.K. (1985), 65, 461-474.

Grauman, G.B., 1967. Factors determining Baltic cod abundance (in Russian). Sb. Nauchnotekhnicheskoy Informatsii VNIRO, 2:25-37.

Grauman, G.B., 1980. Ecology of reproduction of the main pelagophillous fishes in the Baltic Sea (in Russian). Fischerei-Forschung Wissenschaftliche Schriftenreiche 18, 2: 77-81.

Grauman, G.B., 1984. Ichthyoplankton (in Russian). Articles on biological productivity of the Baltic. Vol.3: 259-456.

Grønkjær, P and K. Wieland. 1997. Ontogenetic and environmental effects on vertical distribution of cod larvae in the Bornholm Basin, Baltic Sea. Mar. Ecol. Prog. Ser. Vol. 154: 91-105.

Horbowa, K. and E. Wlodarczyk, 1995. Size-specific vertical distribution and mortality rates of the Baltic cod (*Gadus morhua* L.) eggs in the Bornholm Basin in 1993 and 1994. ICES CM 1995/J:15, 14 pp.

Makarchouk, A. 1996. Ichthyoplankton of the Eastern Baltic in 1991-1995: abundance, distribution and composition. ICES CM 1996/J:25, 13 pp.

Makarchouk, A. 1997. Abundance and composition of ichthyoplankton in the Eastern Baltic in the early 1990s. Proceedings of the 14th Baltic Marine Biologists Symposium, Pärnu: 149-155.

Nissling, A. and L. Westin 1991a. Egg buoyancy of Baltic cod (*Gadus morhua*) and its implications for cod stock fluctuations in the Baltic. Marine Biology 111: 33-35.

Nissling, A. and L. Westin 1991b. Egg mortality and hatching rate of Baltic cod (*Gadus morhua*) in different salinities. Marine Biology 111: 29-32.

Nissling, A., Kryvi, H. and L. Vallin 1994. Variation in egg buoyancy of Baltic cod (*Gadus morhua*) and its implications for egg survival in prevailing conditions in the Baltic Sea. Mar. Ecol. Prog. Ser. 110: 67-74.

Rass, T.S. and I.I. Kazanova 1965. Manual for sampling of fish eggs, larvae and fry (in Russian). Moscow, Pischevaya Promyshlennostj, 44 pp.

Wieland, K. 1995. Einfluß der Hydrographie auf die Vertikalverteilung und Sterblichkeit der Eier des Ostseedorsches (*Gadus morhua callarias*) im Bornholmbecken, südliche zentrale Ostsee. Ber. Inst. F. Meeresk., Kiel, 266: 114 pp.

Wieland, K. and F. Zuzarte 1991. Vertical distribution of cod and sprat eggs and larvae in the Bornholm Basin (Baltic Sea) 1987-1990. ICES CM 1991/J:37, 12 pp.

Wieland, K., Waller , U. and D. Schnack 1994. Development of Baltic cod eggs at different levels of temperature and oxygen content. Dana vol. 10:163-177.

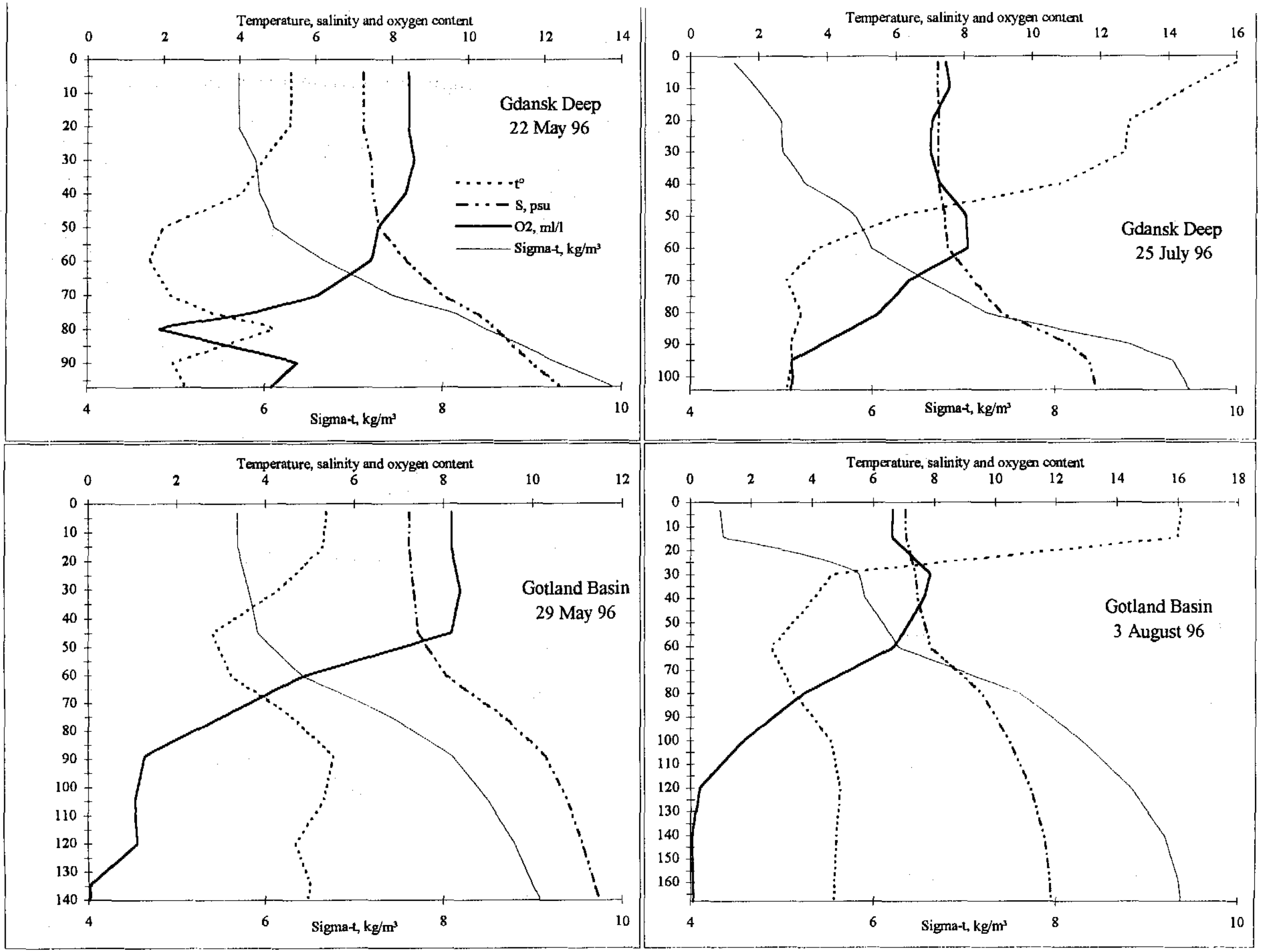

Fig. 1. Hydrological conditions at the sampling positions in 1996.

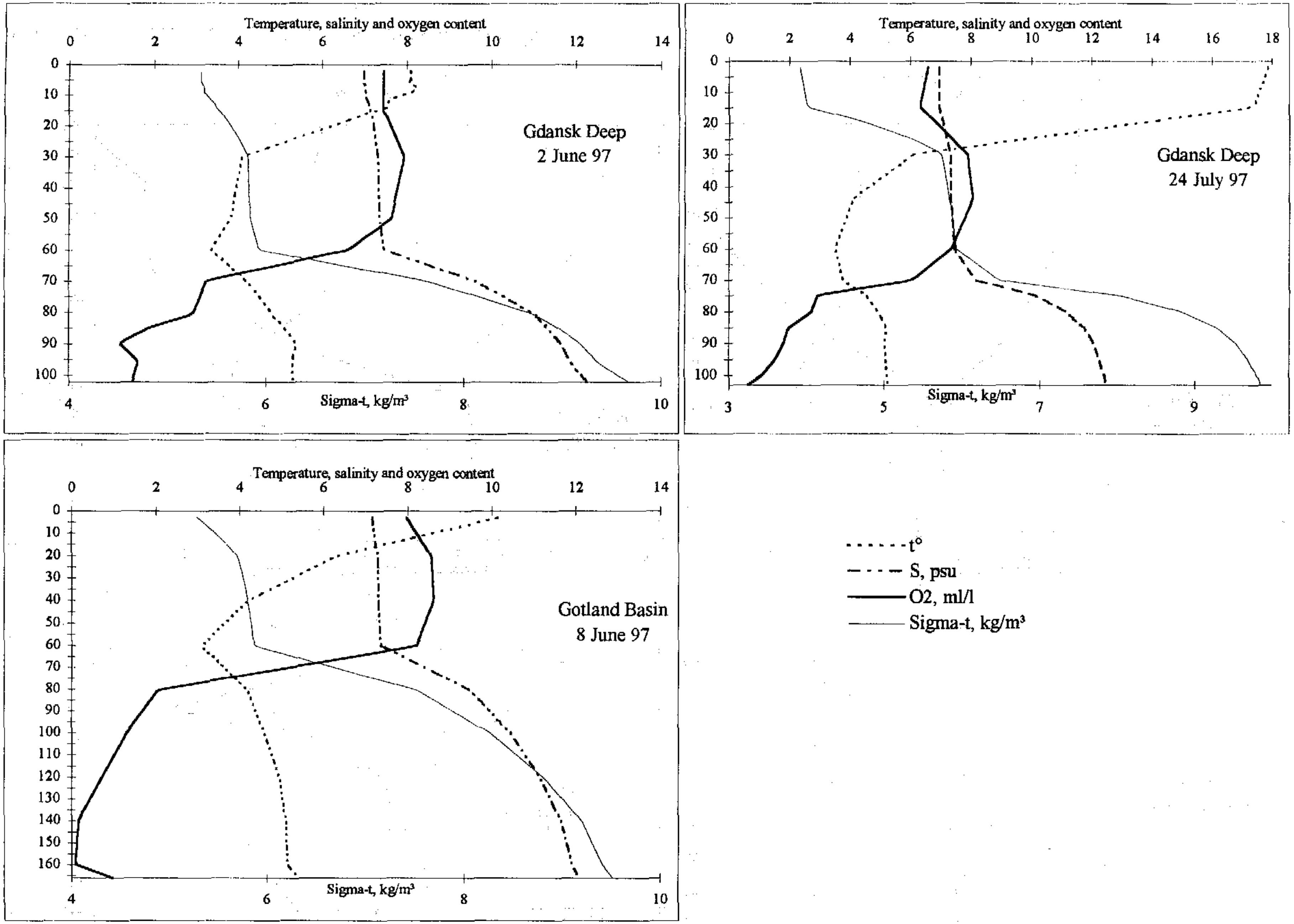

Fig. 2. Hydrological conditions at the sampling positions in 1997.

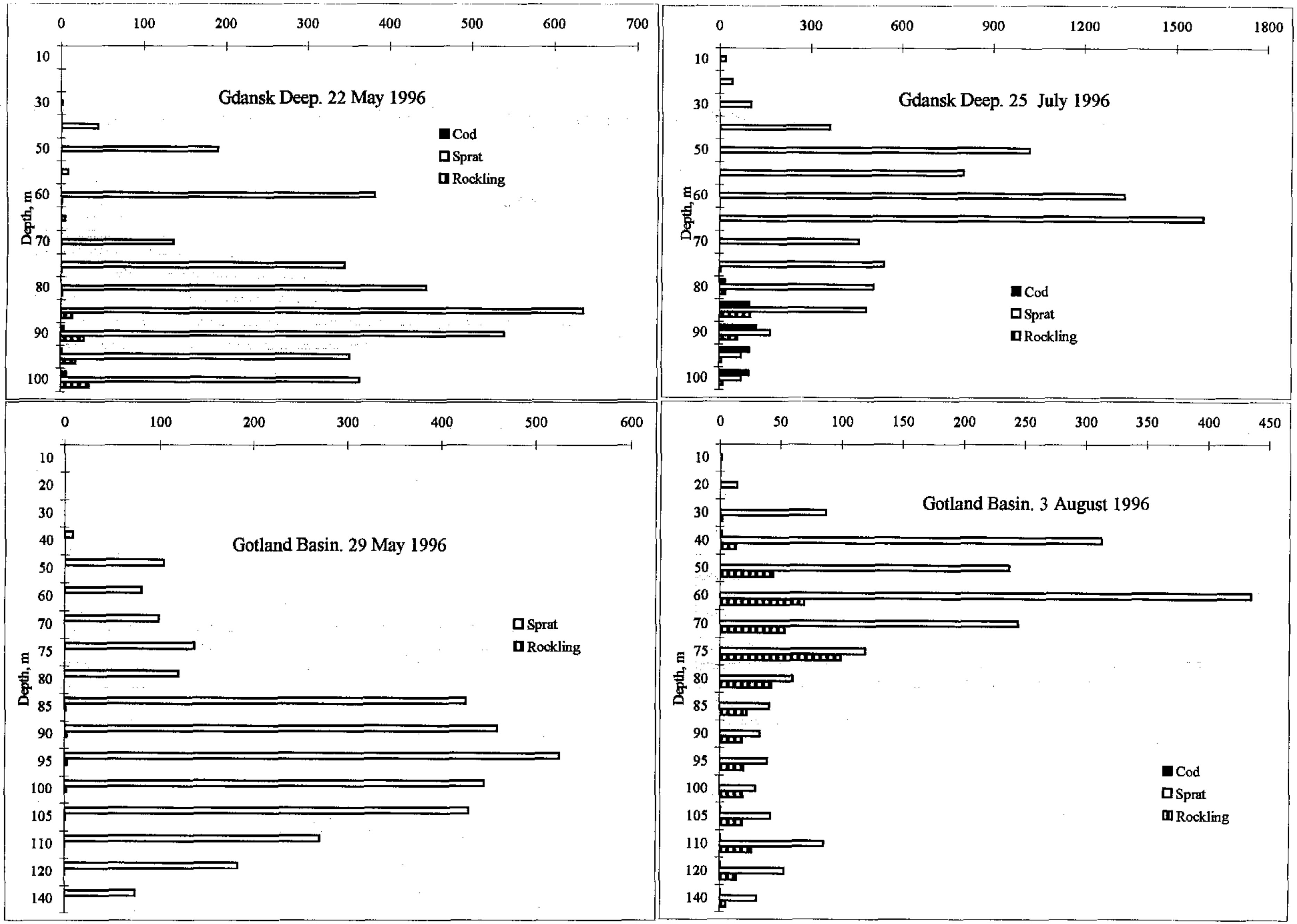

Fig. 3. Vertical distribution (n/100 m³) of pelagic fish eggs in the Eastern Baltic in 1996.

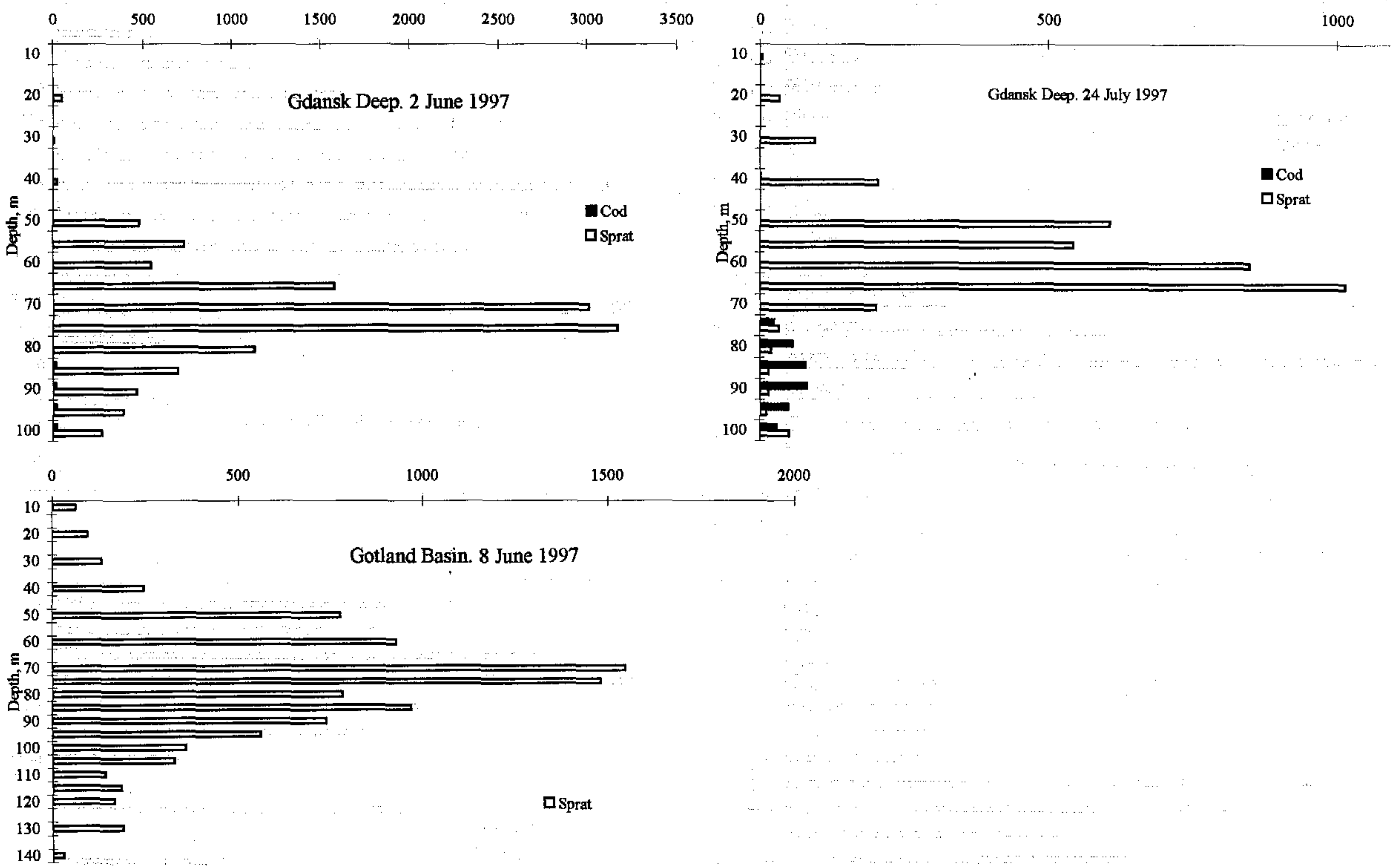

Figure 4. Vertical distribution (n/100 m³) of pelagic fish eggs in the Eastern Baltic in 1997

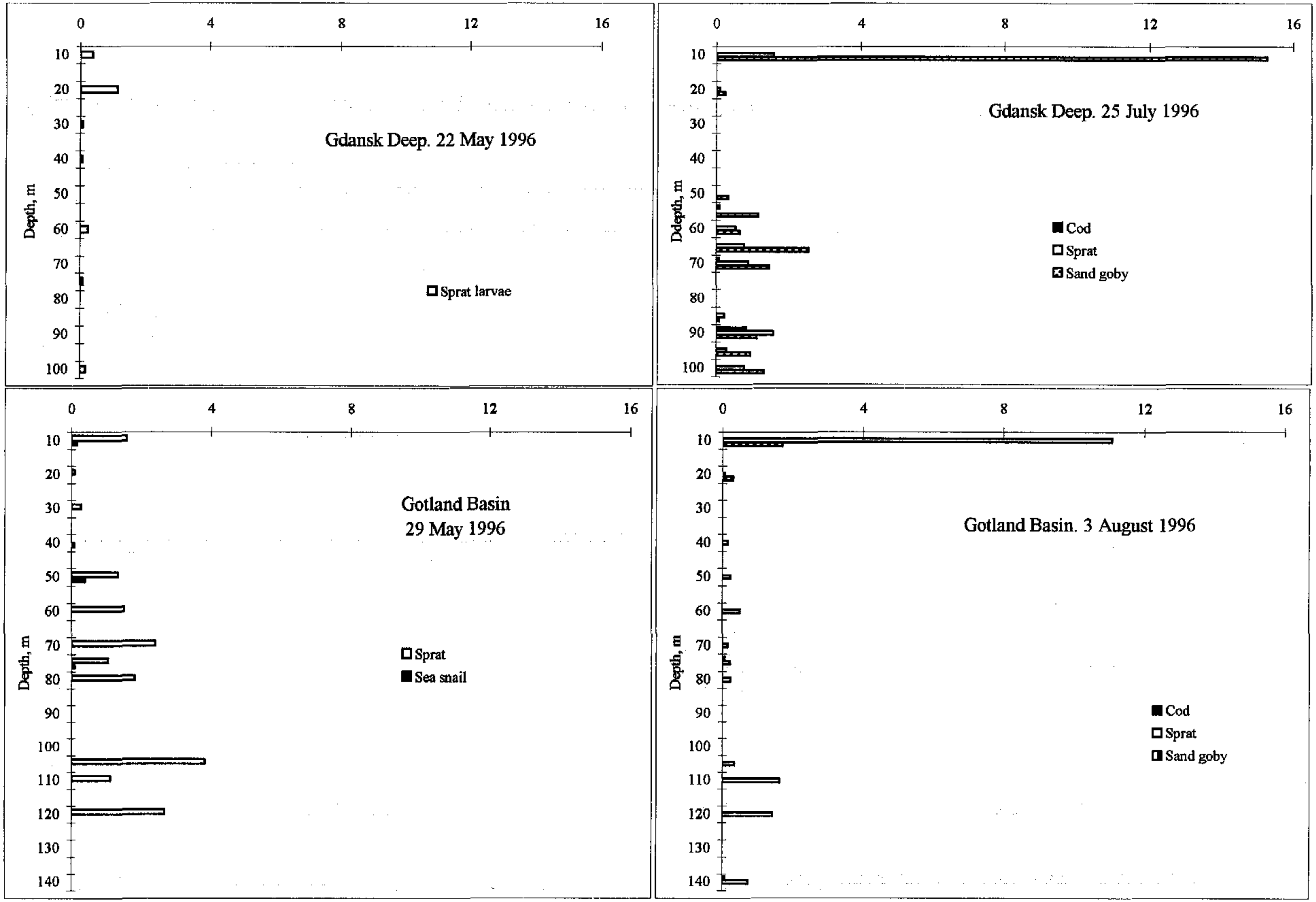

Fig. 5. Vertical distribution (n/100 m³) of pelagic fish larvae in the Eastern Baltic in 1996.

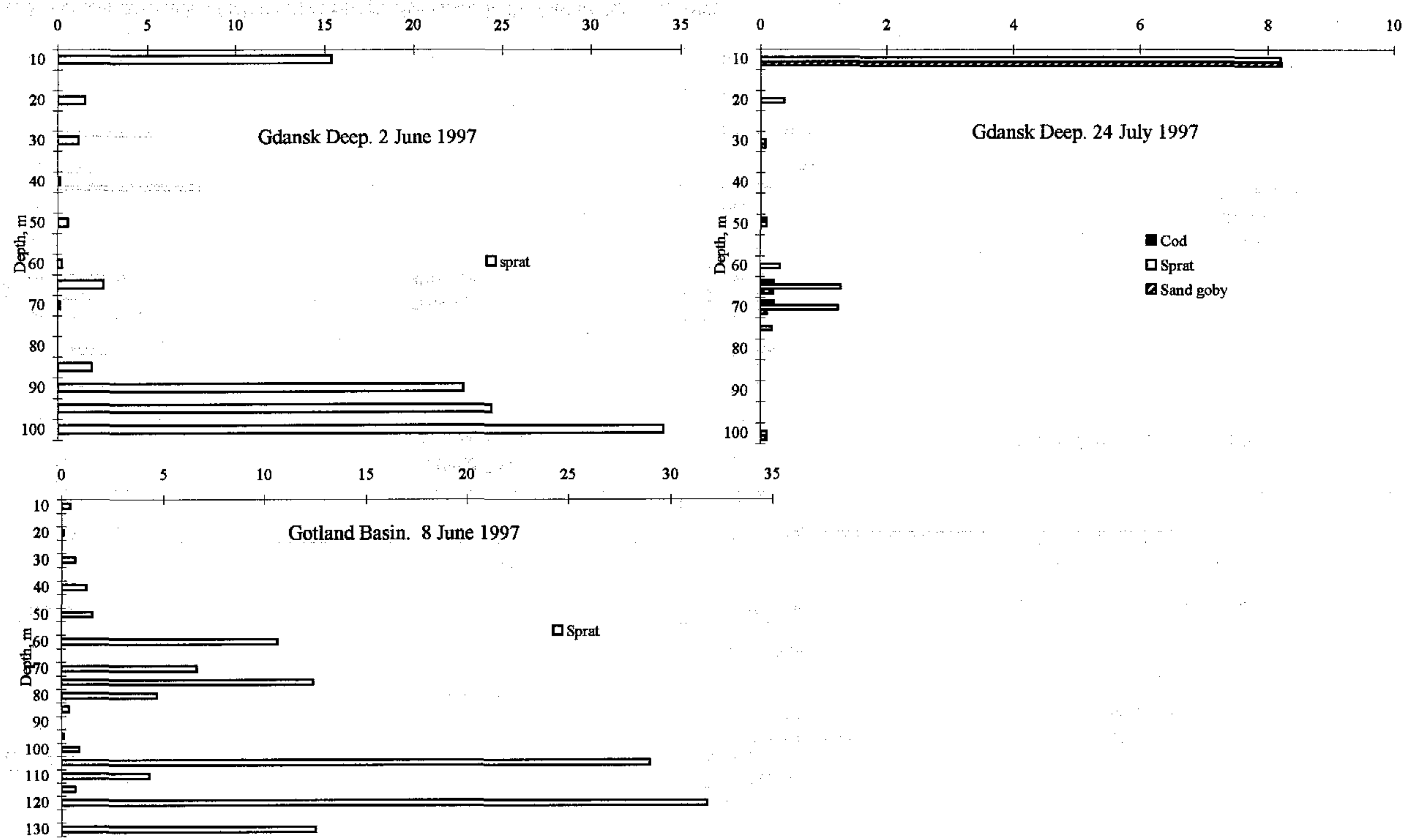

Figure 6 . Vertical distribution (n/100 m³) of pelagic fish larvae in the Eastern Baltic in 1997. BIOMOC studies.

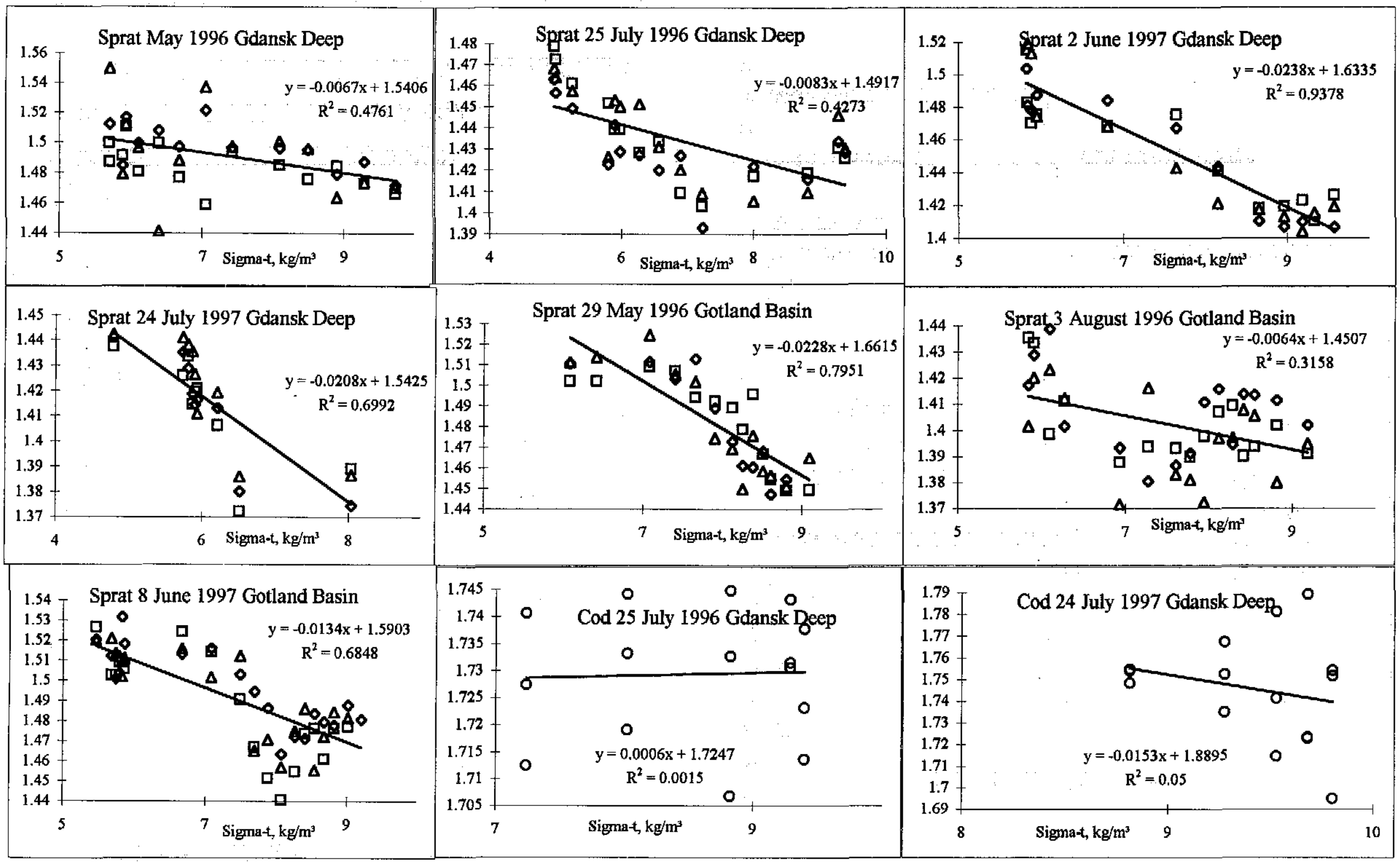

Fig. 7. Sprat and cod eggs diameters (mm) plotted against water density.

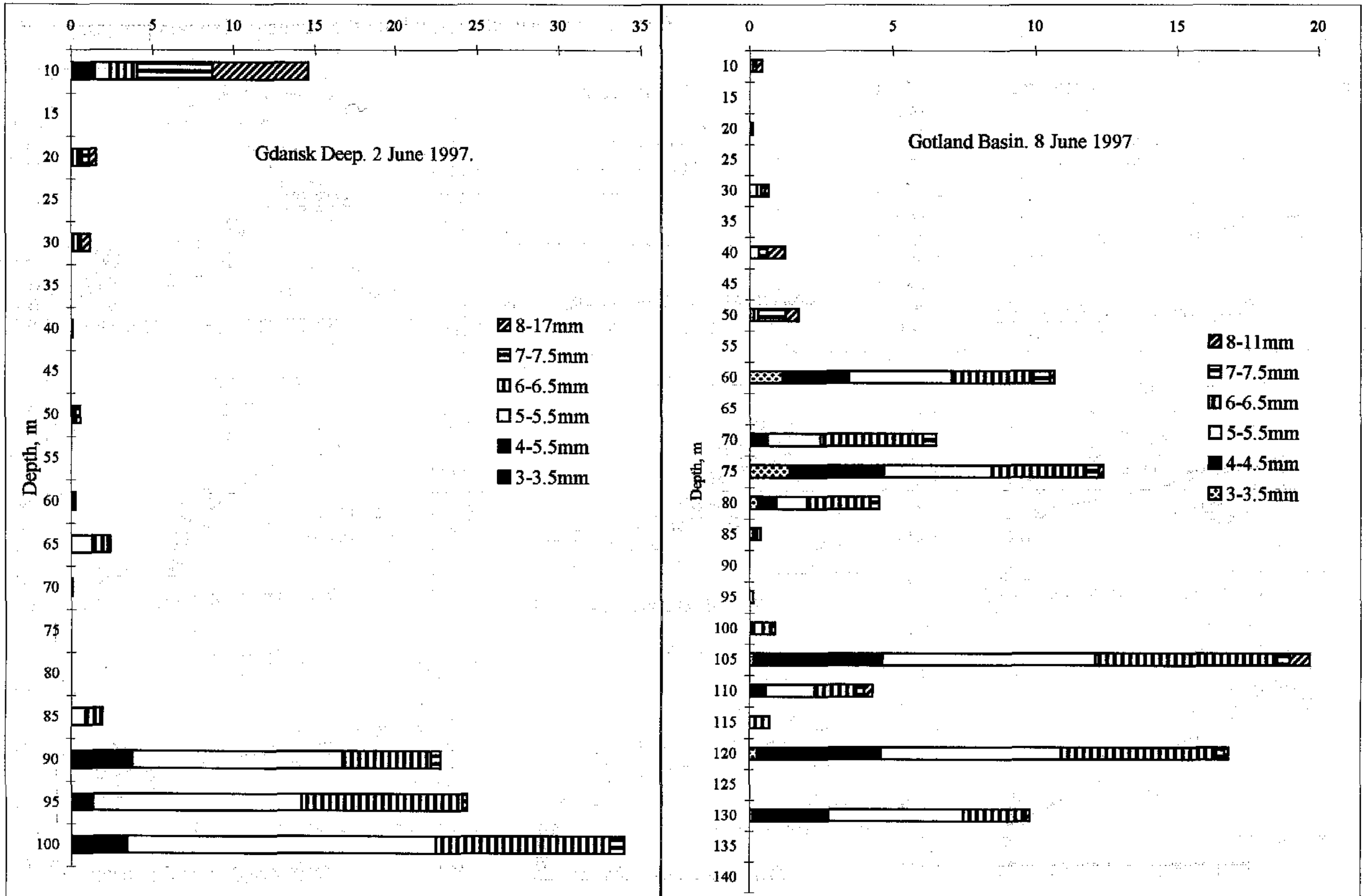

Fig. 8. Vertical distribution of sprat larvae (n/100 m³) of different lengths in the Eastern Baltic in 1997.